Assembly of Dissimilar Aluminum alloys for automotive applications

Project ID: MAT-134
Presenter: Piyush Upadhyay[1]

PI: Piyush Upadhyay[1]
Team: Eric Boettcher[2]
Russel Long[3]

[1] Pacific Northwest National Laboratory
[2] Honda R&D Americas, LLC.
[3] Arconic, Inc.

PNNL is operated by Battelle for the U.S. Department of Energy

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Solid Phase PROCESSING

VTO/DOE Annual Merit Review Meeting, June 1, 2020

Overview

Project Timeline

- Start: Q4FY2017
- Finish: Q3 2020
- 98% Complete

Budget

- Total project funding: $1M
  - DOE: $500k
  - Industrial cost share: $500k
- FY 18: $500k
- FY 19: $500k

Barriers

- Joining method that can meet crash requirements at high volume manufacturing rate with low cost is lacking[1].
- Increased joining speed is needed for process commercialization.

1.Light Duty workshop final report (2013)

Partners

- **OEM**

  Honda R&D Americas, LLC.

- **Supplier**

  Arconic, Inc.

HONDA
Honda R&D Americas

ARCONIC
Innovation, engineered.

Relevance

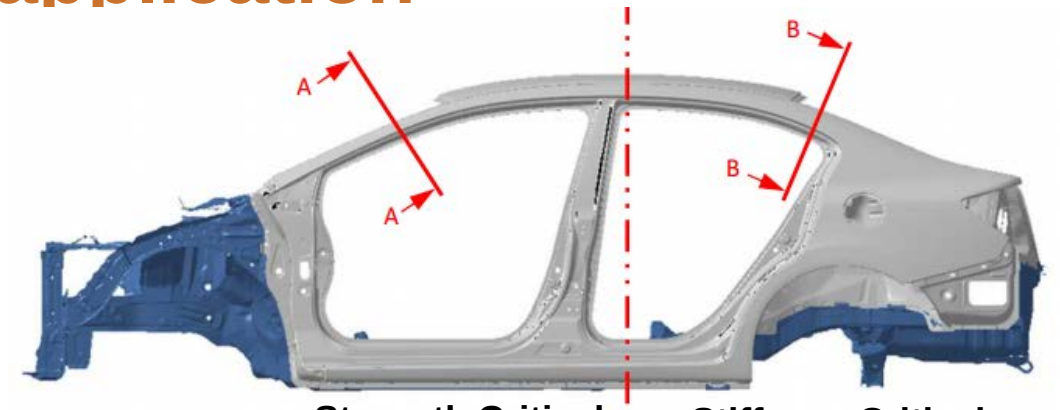
- Overall Objective:

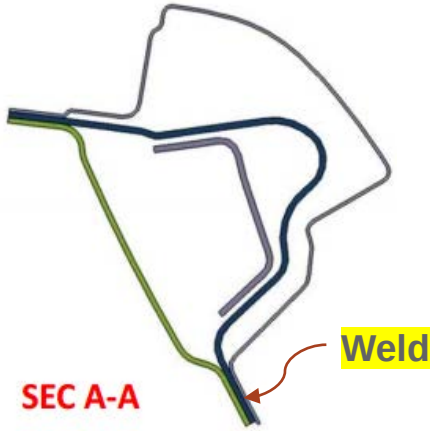
  Develop joining technology needed to demonstrate fabrication of Aluminum alloy assemblies to enable automotive light weighting for high volume industrial commercialization. (addressing technology gap identified by USDRIVE Roadmap (Sec. 5.1) 2017) [1]

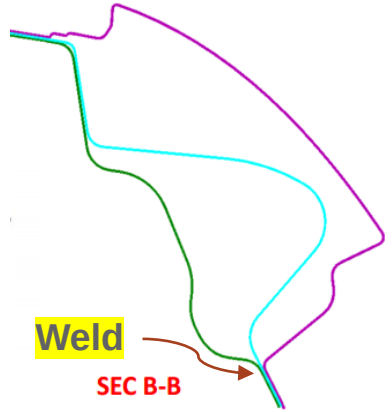
- Objective (FY 2019-FY2020)
  - Meet T peel strength target.
  - Design, implement and execute demonstration Hat welds.
  - Perform 3 pt. bend and crush testing on demonstration Hat welds.
- Impact
  - Joining technology developed and transferred in this project will enable automotive light weighting.
  - By increasing the welding speed, implementing shaped near protype part we are maturing a new joining technique towards commercialization.

Relevance: Intended application

Future Sedan Structure
(Aluminum Cabin on a Steel Platform)







Overall goal

Integrate stamped Al alloys within the existing body construction, so that a function specific Al assembly can be tailored per specific property needs.

Chosen material stack-up

Schedule and Progress

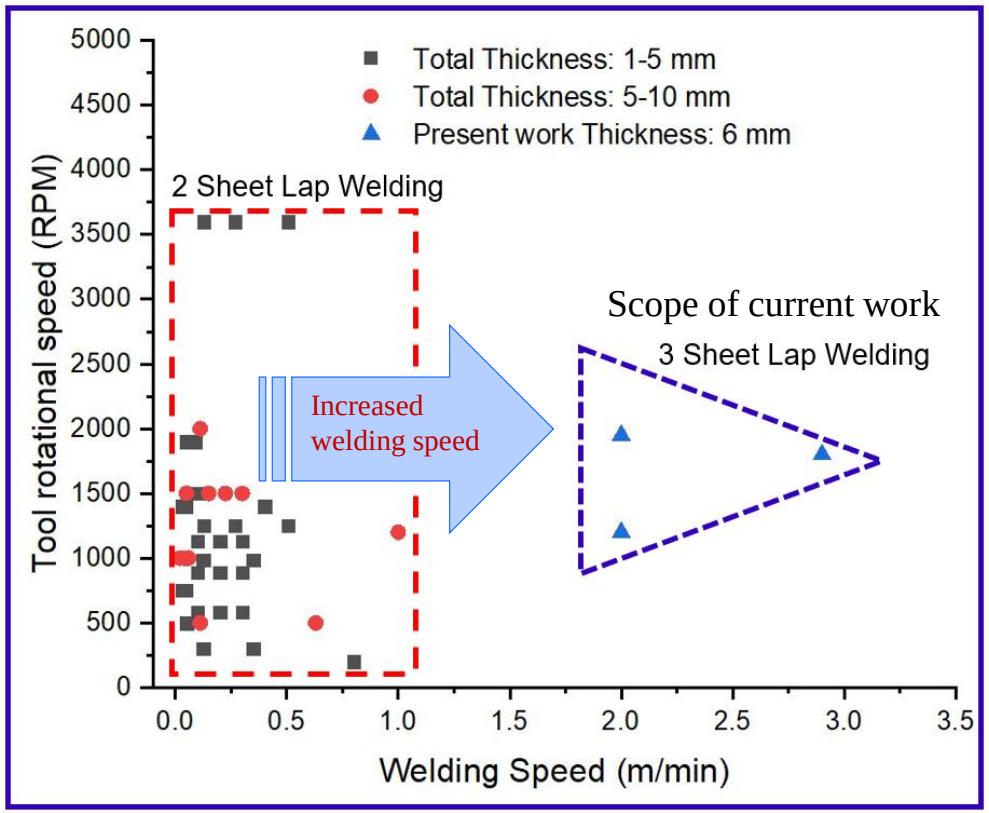
	FY-17	FY2018				FY2019		
Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
1.1. Material configurations & combinations	■	■						
FY18 ✓ → **Milestone 1**		*						
1.2. Weld development		■	■	■				
1.3. Baseline Joint characterization			■	■				
FY18 ✓ → **Milestone 2**					*			
1.4 Near trim edge weld line sensitivity study			■	■	■	■		
1.5 Analysis of process factors and outcomes:			■	■	■	■		
FY18 ✓ → **Milestone 3**						*		
Decision Gate: Joint Performance								
2.1 Extended material combinations				■	■	◆	■	
2.2. FSLW tool optimization				■	■	■	■	
3.1 Prototype design				■	■	■	■	
FY19 ✓ → **Milestone 4**							*	
3.2. Technology Transfer					■	■	■	■

Project Milestones

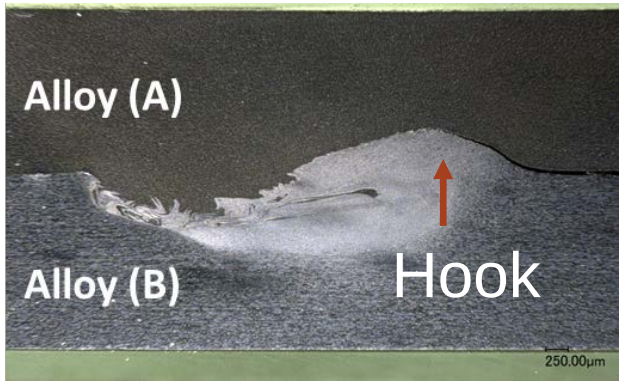
- **Milestone 1 (Q2):** Specific material combinations and configurations including sheet thicknesses and temper are finalized. Testing requirements are finalized for joint assessment for the remainder of the project. (Complete)
- **Milestone2 (Q5):** By the end of task 1.3 welding parameters are down selected on the basis of testing matrix established in Milestone 1, such that effective joints are obtained with welding speed greater than 1.0m/min. (Complete)
- **Milestone 3 (Q6):** Sensitivity study for weld line near the trim edge is complete. Analysis of process factors and joint outcomes is completed. (Complete)
- **Milestone 4 (Q7):** Prototype design is complete. FSLW tool optimization for joints developed in the project is complete. (Complete)

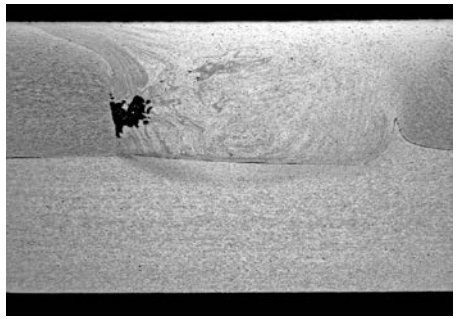
High speed FSLW: Fundamental Barrier

- The project utilizes Friction stir welding method at high speed (welding speed ≥500mm/min) for Al alloys assembly.



Issues with joining multiples sheets





Hooks
Sheet thinning
Inadequate oxide mixing.
Worm Hole defect
7xxx series
Incipient melting
Tool forces/mixing.

We setout to establish welding parameters that can minimize interface hooking (upturn) and eliminate weld defect at high speed for 2 sheet and 3 sheet joining.

Technical Approach: Task Flow

Task 1:
Stack-up and Baseline development

- ✓Task 1.1 Material and configurations
- ✓Task 1.2 Flat weld development
- ✓Task 1.3 Baseline characterization.

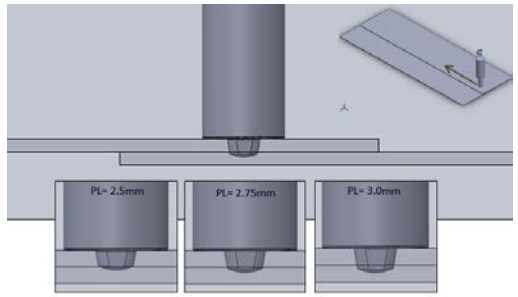
Task 2:
Extended weld development

- ✓Task 2.1 Material variations
- ✓Task 2.2 Tool development
- ✓Task 2.3 Testing

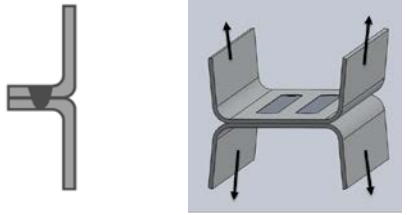
Task 3
Prototype design and demonstration

- ✓Task 3.1 Prototype Design
- ✓Task 3.2 Prototype Fabrication
- ✓Task 3.3 Tech. Transfer

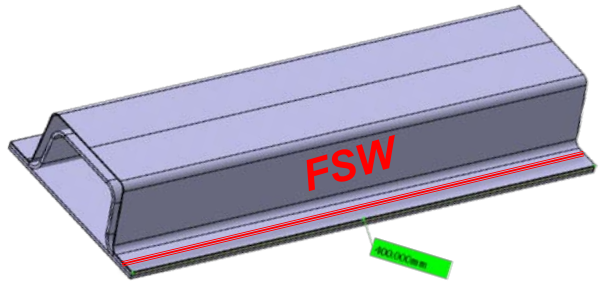
Flat coupon joints



Characterization
Optical, Lap shear



Characterization
Optical, Hardness, Lap shear, T- Peel, KS2



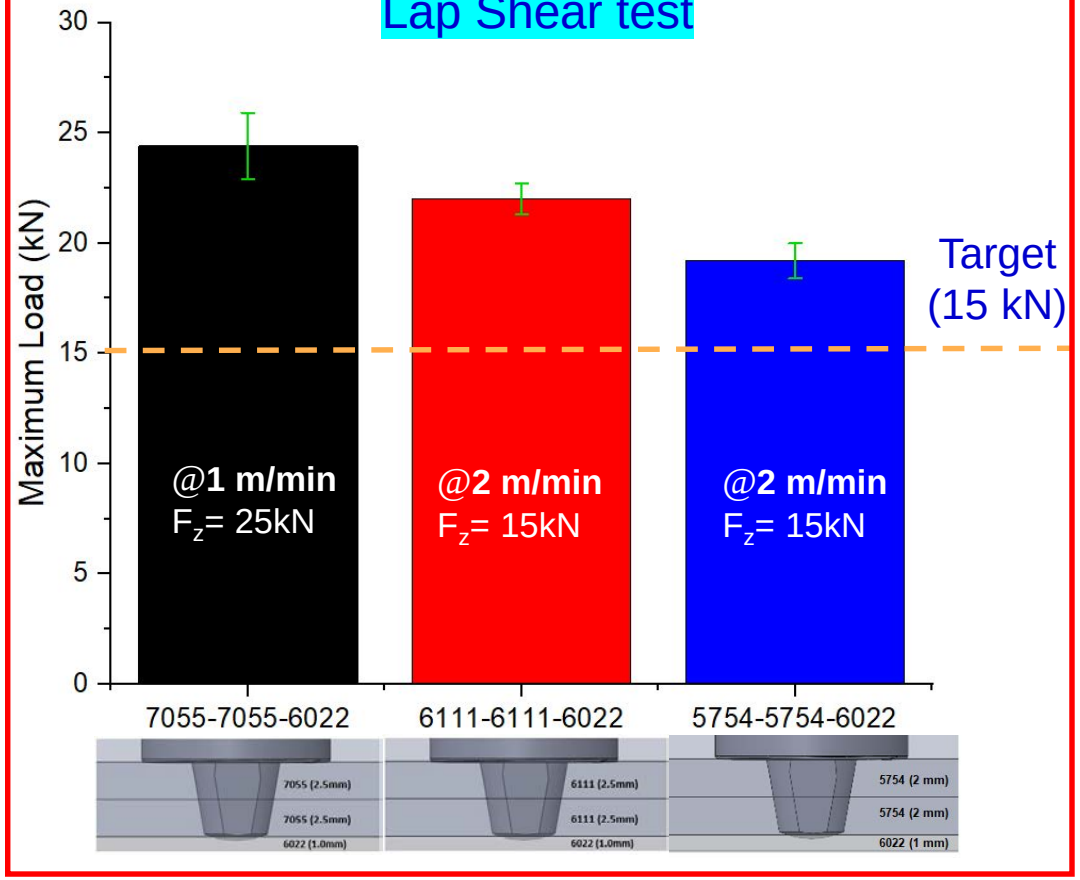
Characterization
3pt bend, Crush tests

Pacific Northwest NATIONAL LABORATORY

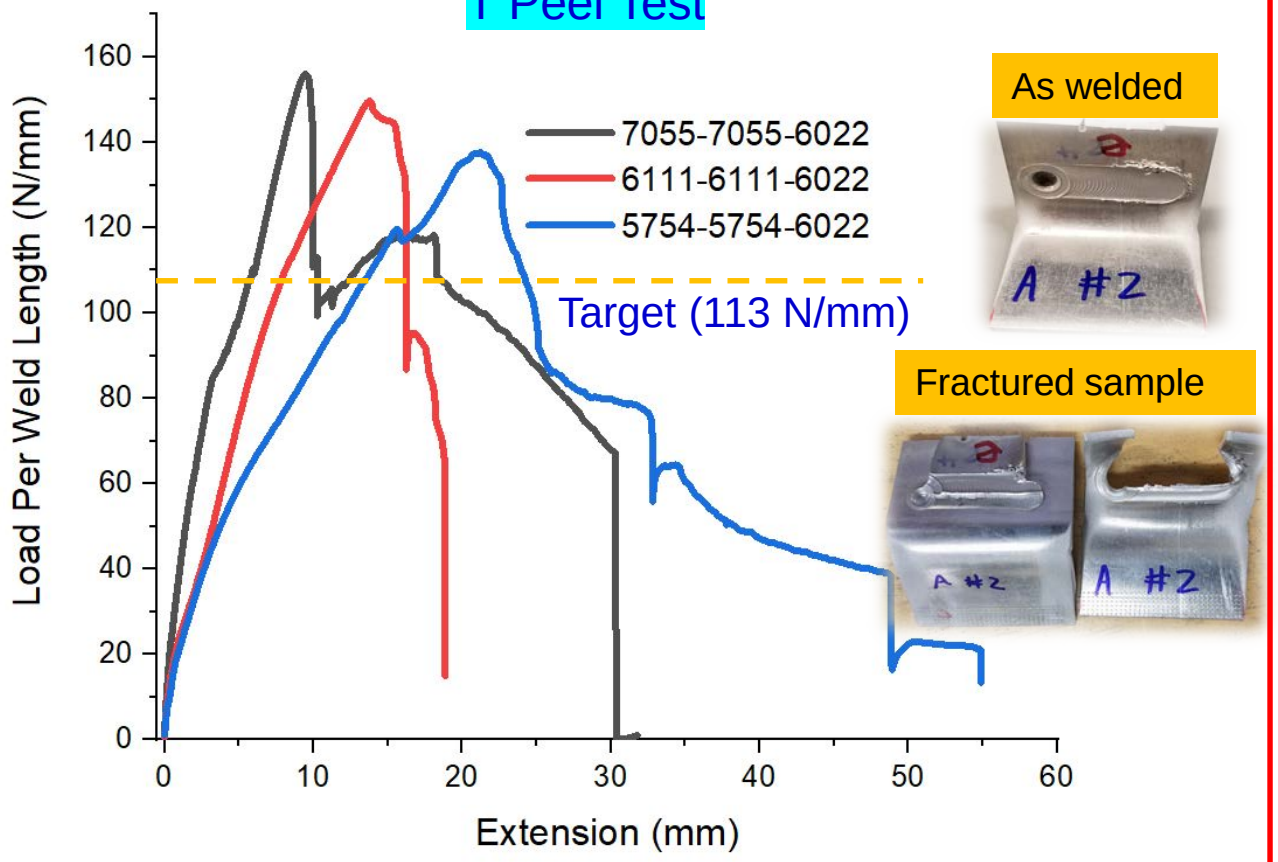
ACCOMPLISHMENTS

Joint strength at high welding speed exceeds set target

Lap Shear test



T Peel Test



This year we demonstrated 3 sheet joining at a welding speed of 1m/min and higher for all the 3 material set. The lap shear strength exceeds RSW minimum requirements with 15mm spacing per AWS D17.2 requirement.

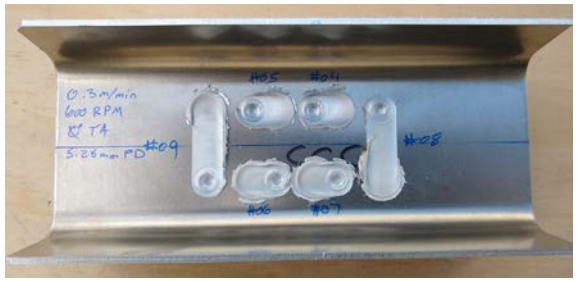
Pacific Northwest NATIONAL LABORATORY

ACCOMPLISHMENTS

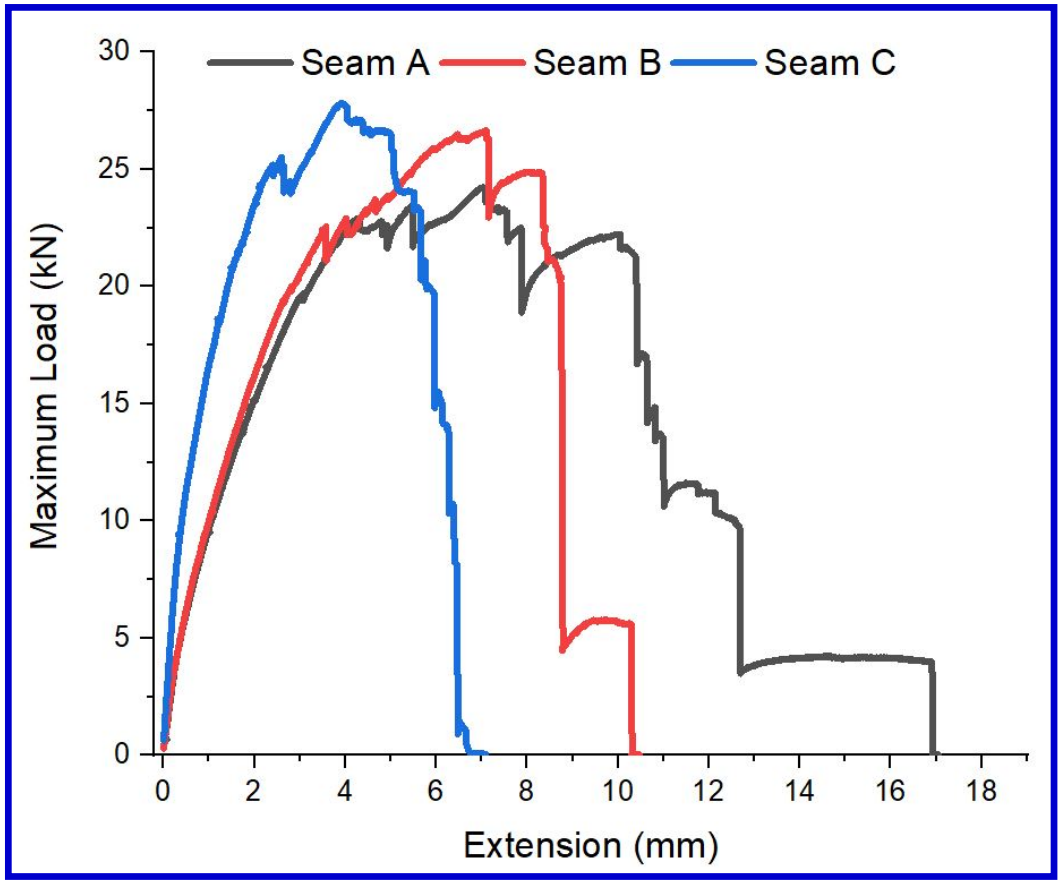
Tested different weld seam configurations

Seam A

Seam B



Seam C

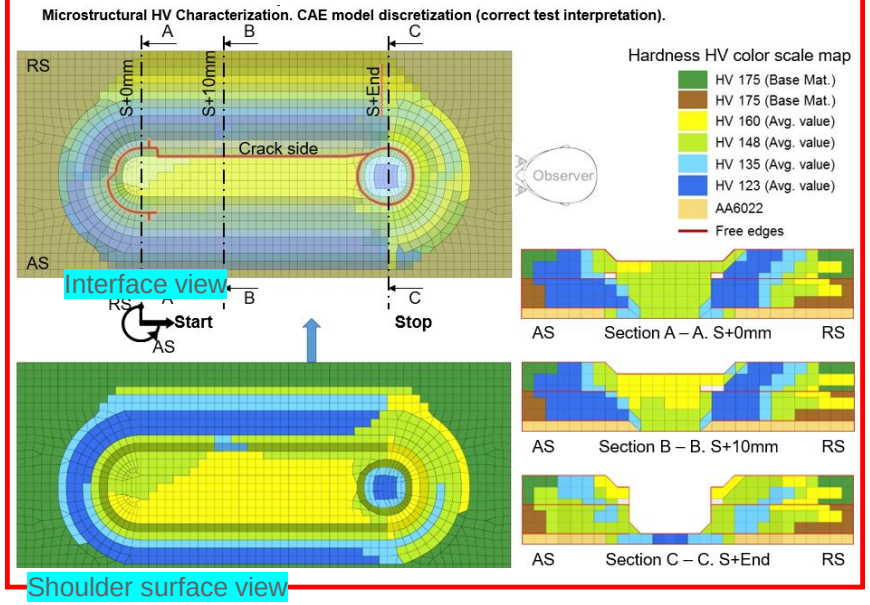


3x seam designs were tested in KS2 configurations to examine the effects of start and stop on joint load curves.

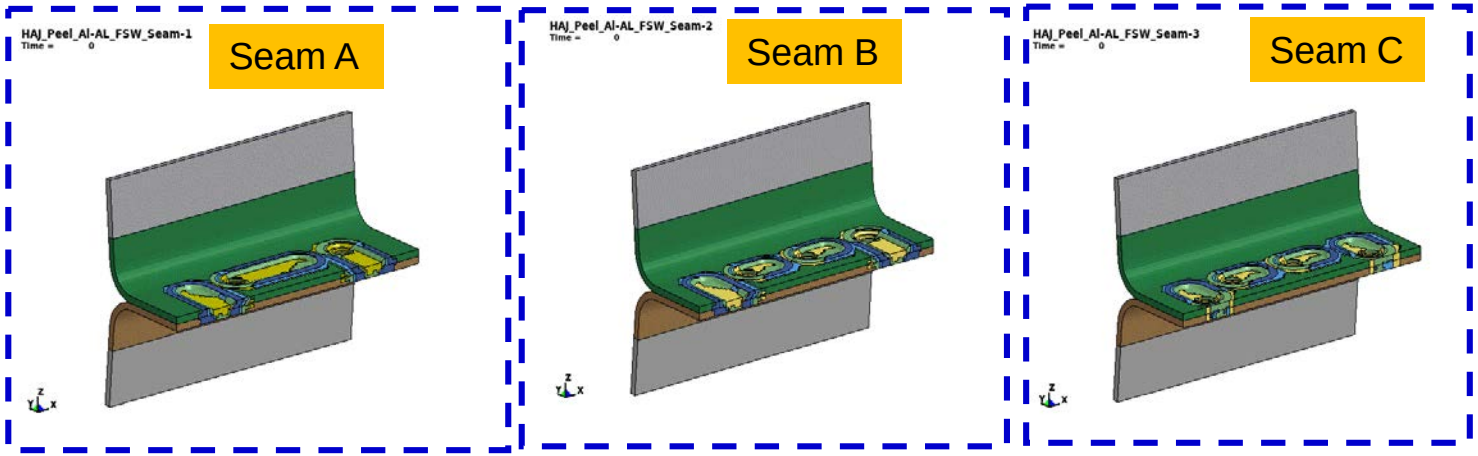
ACCOMPLISHMENTS

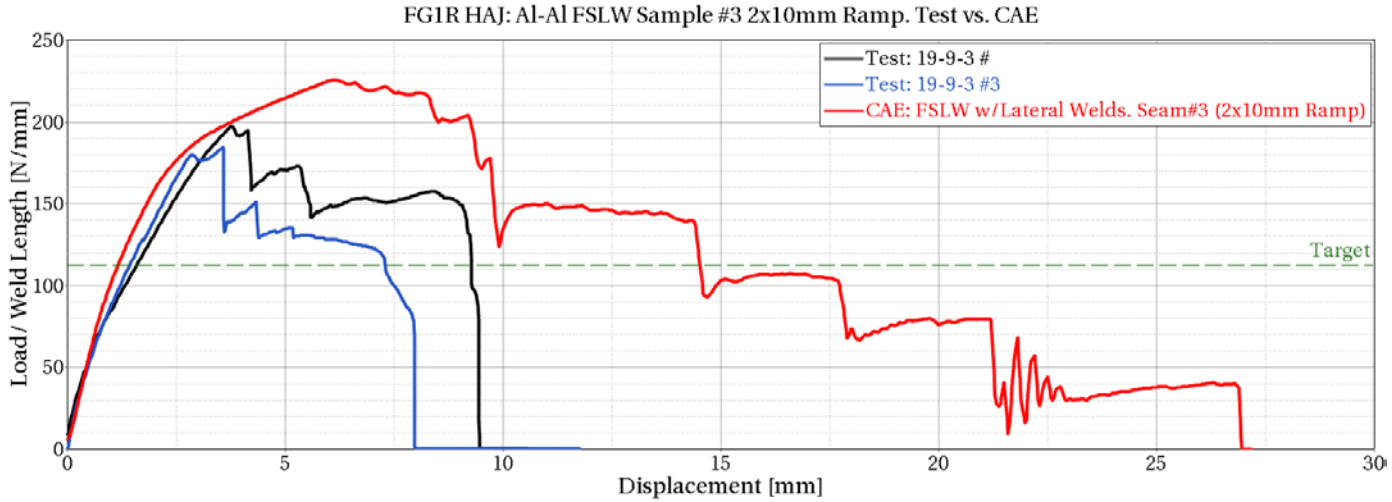
Preliminary modeling provided predictive capability

CAE model preparation based on the microhardness



The model included oxide layer, and voids present at start, weld path and stop portions.





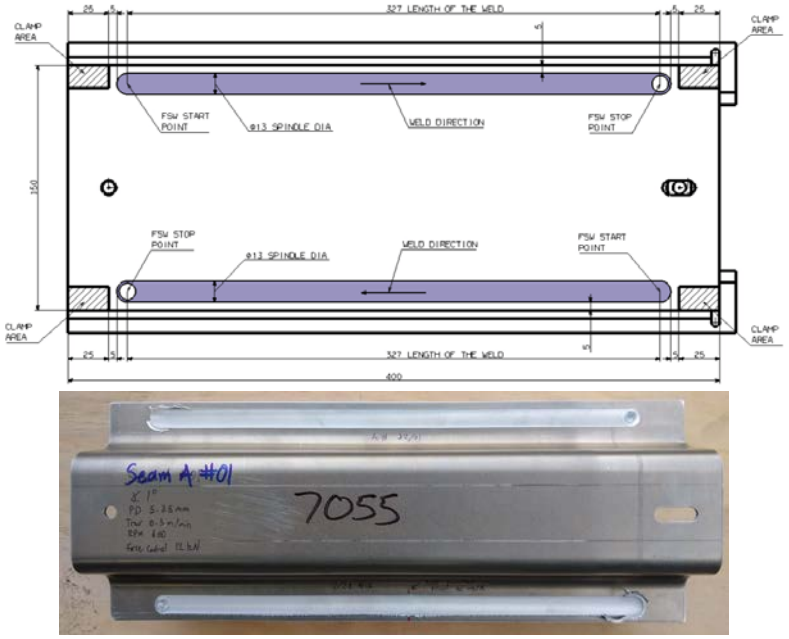
CAE modeling based on full field hardness measurements shows promising results towards predictive capability.

Pacific Northwest NATIONAL LABORATORY

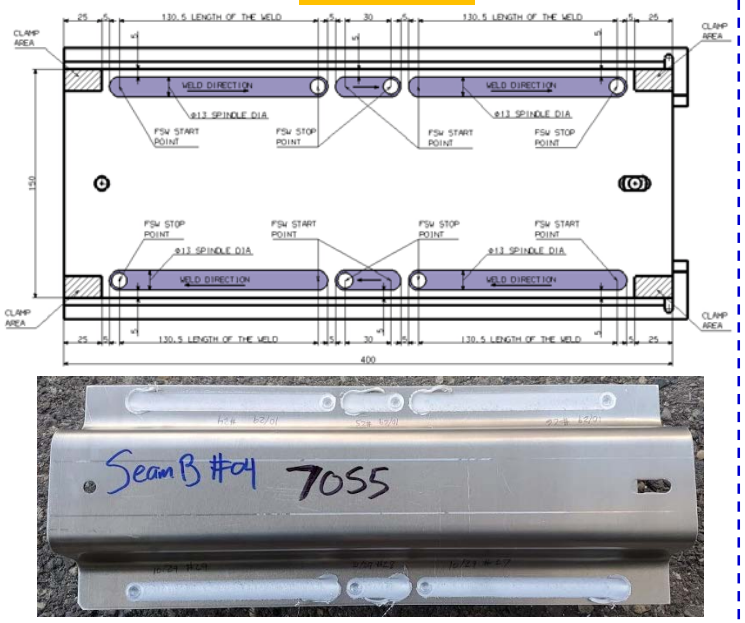
ACCOMPLISHMENTS

Finalized design for Demo Hat part

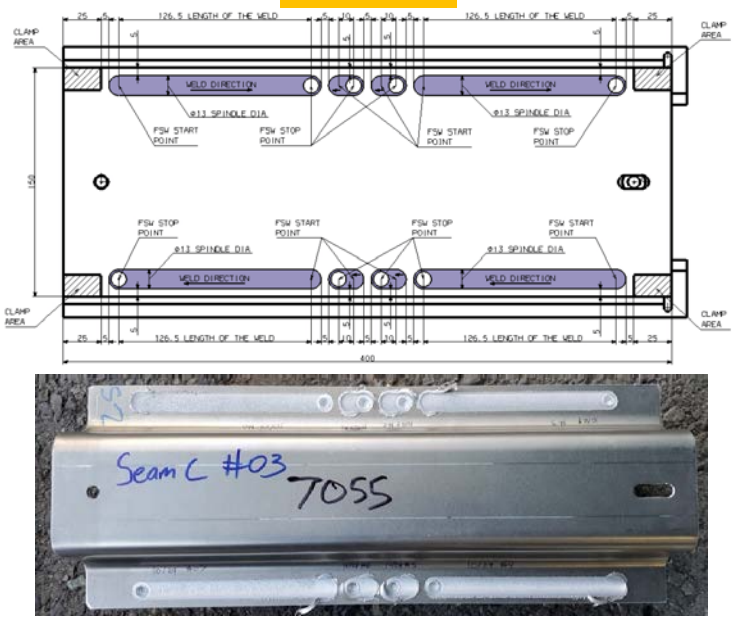
Seam A



Seam B



Seam C

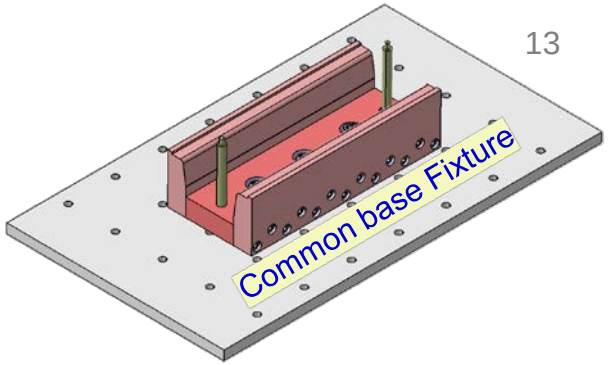


Based on Seam design study in KS2 configurations and unit force study in T- peel configuration 3 seam designs were selected for Demo Hat welds.

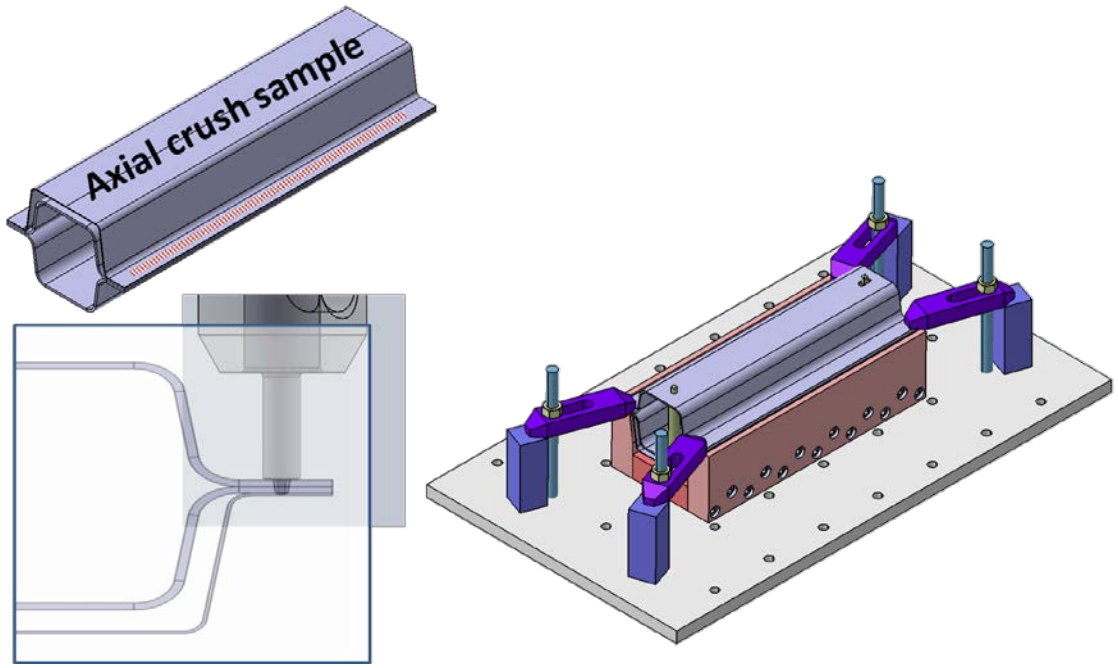
Pacific Northwest NATIONAL LABORATORY

ACCOMPLISHMENTS

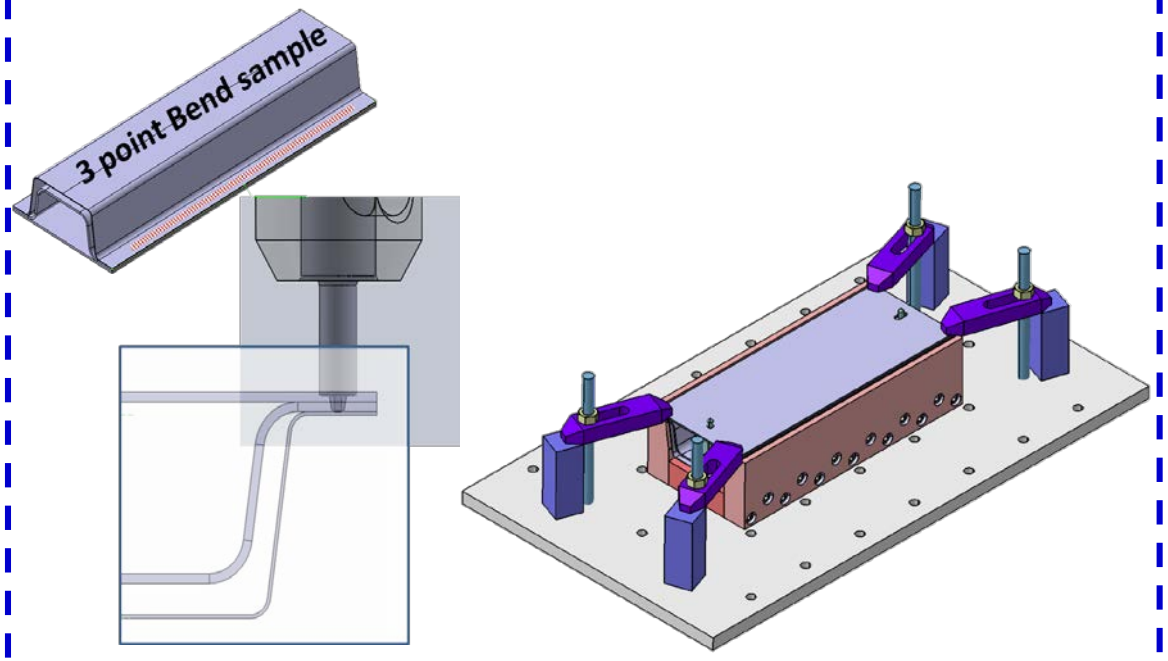
Designed Hat Welds-Fixture



Hat-Hat-Hat Welding setup



Hat-Hat-Flat Welding setup



Measured planer forces generated were used to predict minimum clamping force required to retain the hat section in place. Finger clamping design was chosen for implementation.

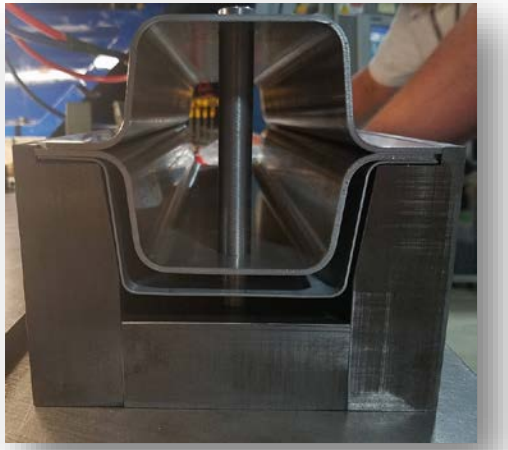
Pacific Northwest NATIONAL LABORATORY

ACCOMPLISHMENTS

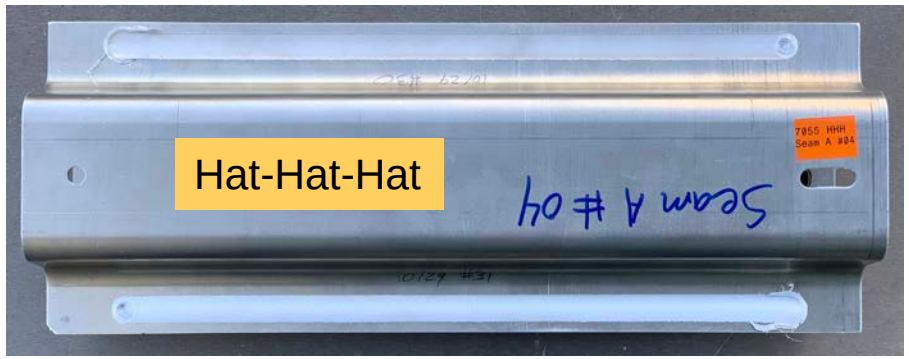
Implemented Demo Hat Fixture


Base fixtures


Hat section clamped on FSW bed



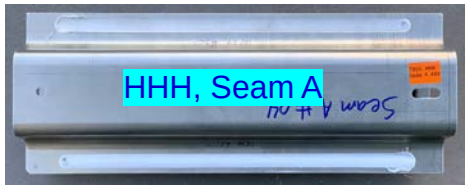

FSW tool at seam

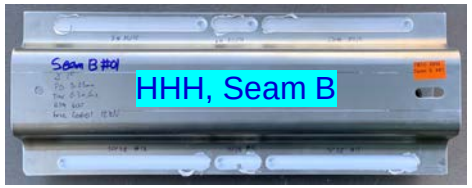


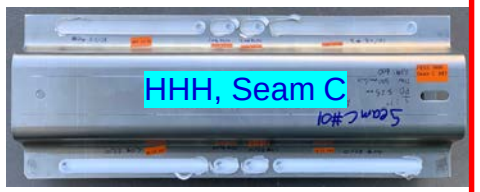
We implemented finalized fixture design at PNNL FSW machine platform for 3 pt. bend and crush samples.

ACCOMPLISHMENTS
Demo Hat sections were produced

7055-7055-6022 Joints







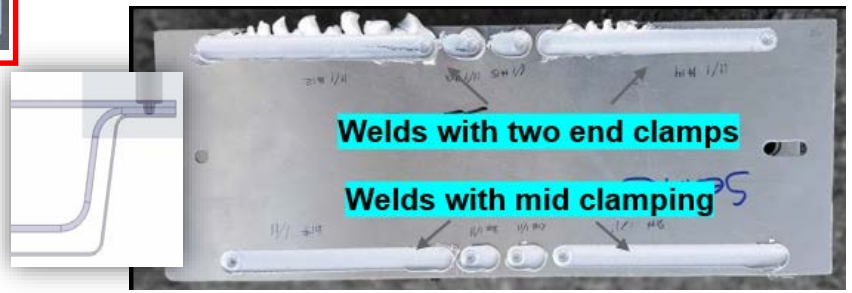
5754-5754-6022 Joints

6111-6111-6022 Joints

Number of samples produced for testing

Material	Seam	HHH	HHF
7055-7055-6022	A	5	0
	B	5	4
	C	5	4
6111-6111-6022	C	2	2
5754-5754-6022	C	2	3

- 32x demonstration hats were produced and shipped for testing.
- Seam A: For HHH End clamping was sufficient to provide stiffness. Tool was replaced after every two Demo parts to avoid break.
- Seam B/C: For HHF part end clamping was not enough. Mid clamping was needed.



Excessive flash at the edge was solved using mid clamping

Response to reviewer comments

- No reviewers comments from last year to respond.

Collaboration and coordination

- Through the in-kind funds available to partners
  - Honda
    - Provides assessments on production relevance of material stack up and configurations
    - Provides input on joint evaluation/ characterization matrix and test requirements.
    - Leads on prototype design and evaluation metric and testing.
    - Provides modeling support for design of weld and test fixtures.
  - Arconic
    - Provides relevant Aluminum alloys

Remaining challenges and barriers
Lessons learned: Known and unknown

Process Robustness

Well Known
- ✓Weld length
- ✓RPM/ welding speed range
- ✓Part form (flat vs. hat)

Somewhat Known
- ✓Thickness Variation
- ✓Porosity
- ✓Clamping
- ✓Edge Distortion

Unknown
- Closed Loop Feed back control

FSW Tool

Well Known
- ✓Tool geometry for load target
- ✓Tool Features for defect free welds

Somewhat Known
- ✓Features and indicators to avoid incipient melting
- ✓Indicators of incipient melting
- ✓Tool Wear per alloy
- ✓Tool Failure

Unknown
- Tool life at Scale
- Fatigue loading analysis

Function

Well Known
- ✓ Cross-section vs. joint strength correlation
- ✓Nugget size
- ✓Defects
- ✓Hooks

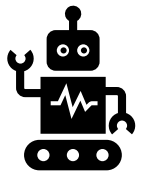
Somewhat Known
- ✓Defect sensitivity to performance- quality control
- ✓Weld configuration and weld length effects
- ✓Parts “Gap” at flanges, viable ranges, process window etc.

Unknown
- Fatigue strength
- Effect of Loading side
- TSS , T-Peel , U peel

Scale Up

Somewhat Known
- Clamping Scheme
- Minimum clamping required?
- Edge Distortion
- Pilot Hole
- Flash Management
- Force Control on stamped part at speed

Unknown
- Robot



Planned Future Work

- Complete Crush and 3-point bend testing of DEMO hat sections at HRA.
- Complete formal reporting.

Any proposed future work is subject to change based on funding levels.

Pacific Northwest NATIONAL LABORATORY

Project Summary

The goal of this project was to develop FSLW such that viable joints in several Al alloys can be made at industrially viable speeds and configuration for commercialization.

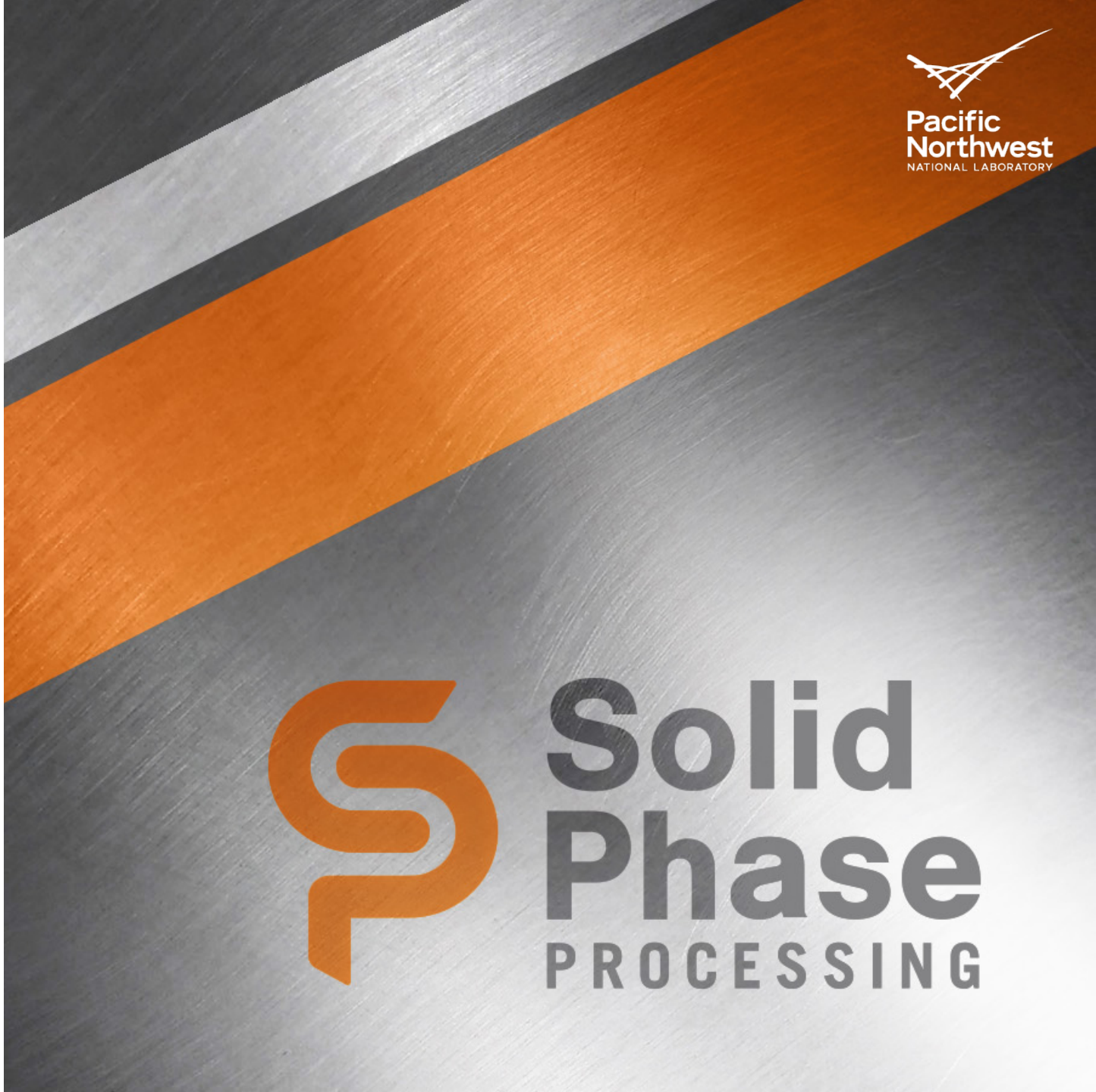
- The project team consisting of a national lab, an automotive OEM and material supplier demonstrated this goal and brought the technology closer to commercialization.

Key Technical Challenges	Project accomplishment
Demonstrate target loading in lap shear and T peel testing.	We have exceeded target lap shear and T peel loading requirements for all 3 material set for 3 sheet configuration.
Demonstrate high welding speed for industrial viability	Welds were made at 2m/min for 6111 and 5754 material combination and 1m/min for 7055 configuration.
Demonstrate clamping, fixturing, welding and testing of shaped near prototype part.	• Fixture and clamping arrangements were successfully developed to produce Demo Hats. • KSII configuration were implemented for the first time in FSW joints.

Any proposed future work is subject to change based on funding levels.

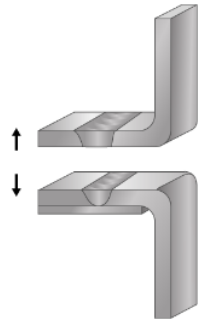
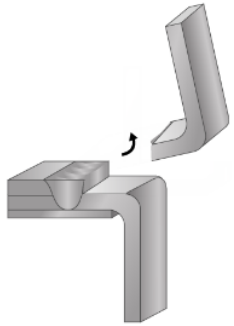
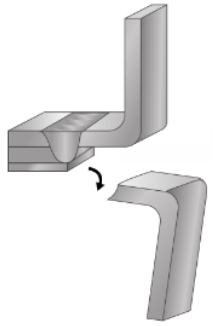
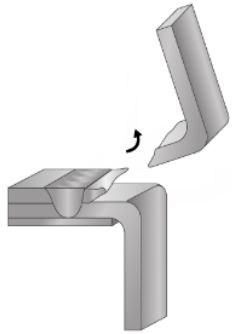
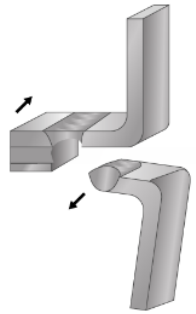
Pacific Northwest
NATIONAL LABORATORY

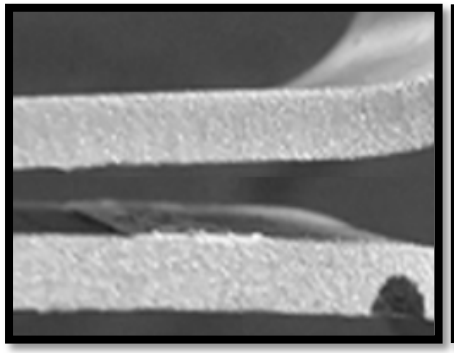
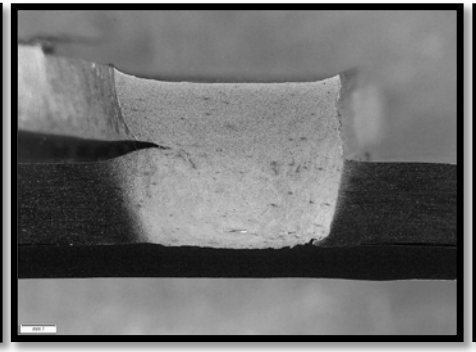
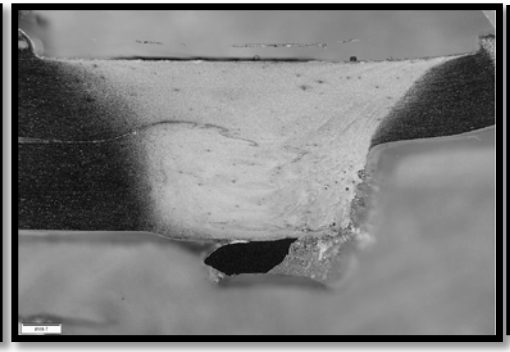
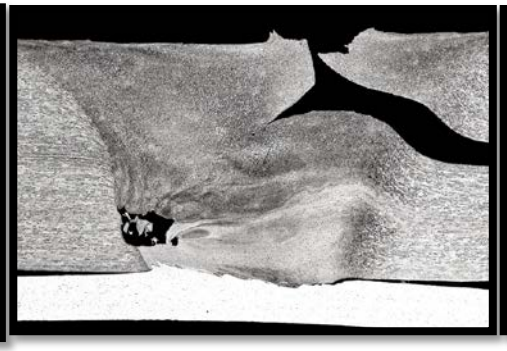
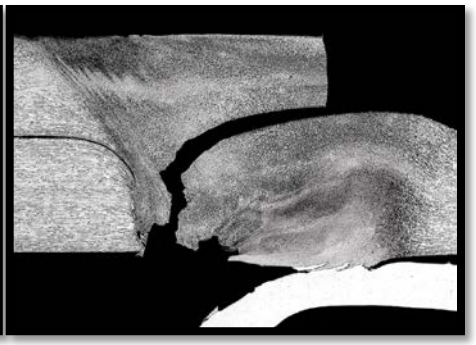
Technical Backup Slides



Pacific Northwest NATIONAL LABORATORY

Fracture modes observed in the FSLW joints.

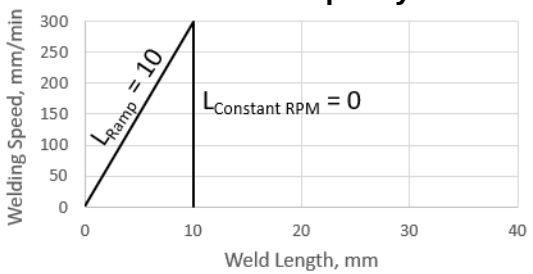
Fracture types:	Interfacial	Heat-affected zone fracture – top sheet	Heat-affected zone fracture – bottom sheet	Ductile on top sheet	Interfacial & bottom sheet
ON PEEL					

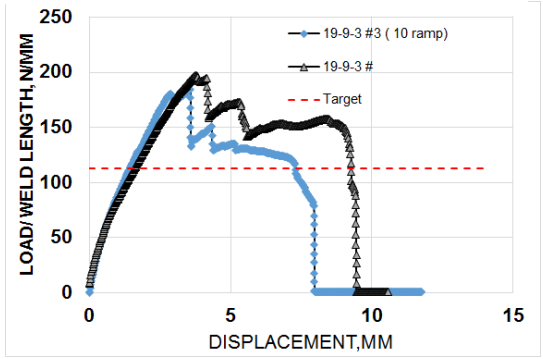






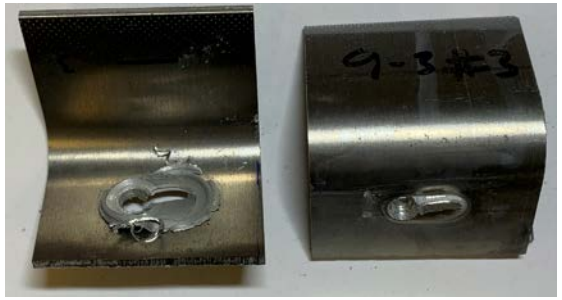
Pacific Northwest NATIONAL LABORATORY

Unit force study (transverse, whole weld- 7055)

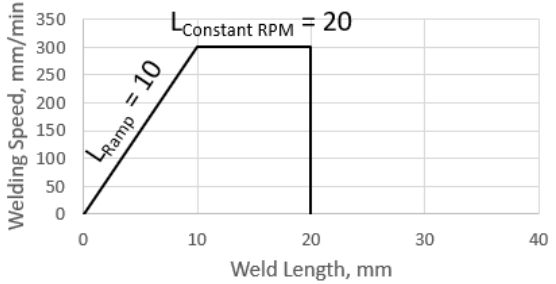
10 mm ramp only

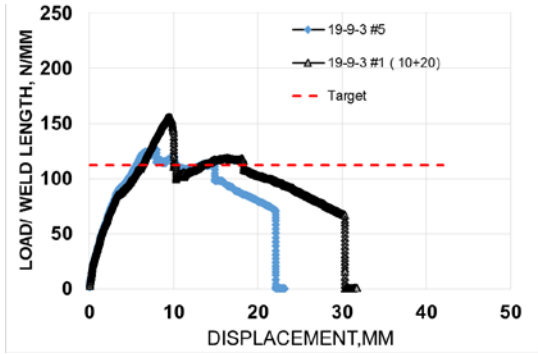


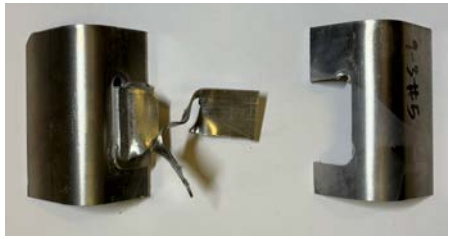




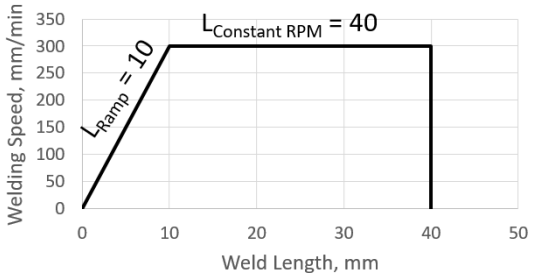
10mm Ramp+ 20mm constant RPM

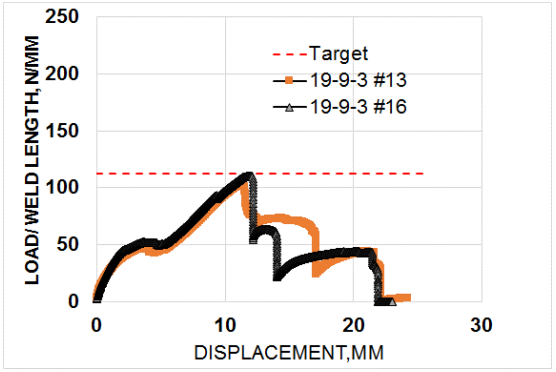




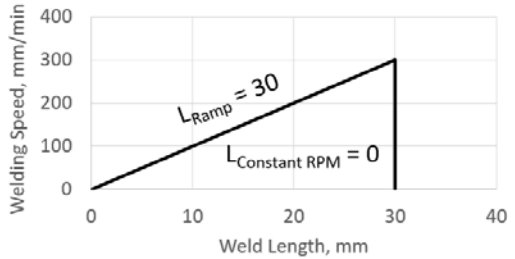


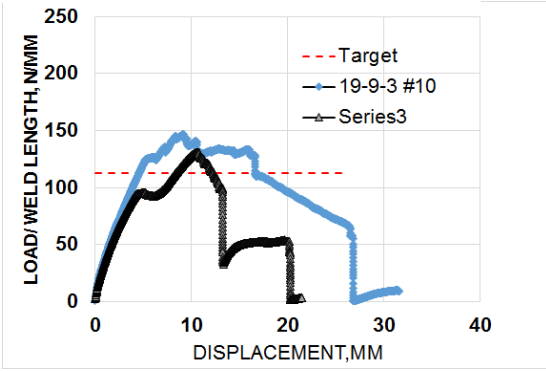
10mm Ramp+ 40mm constant RPM



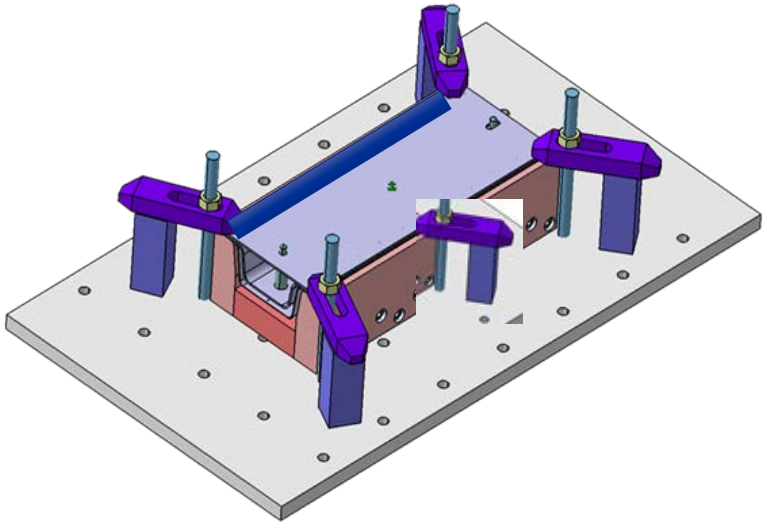


30 mm ramp only

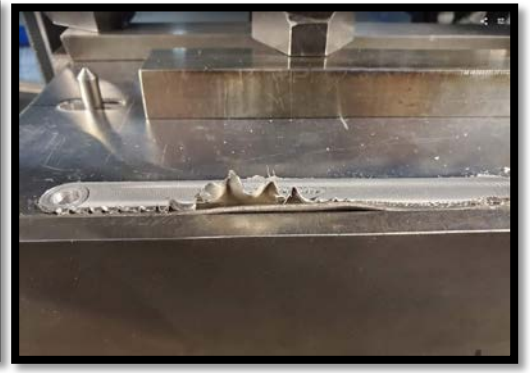




Demo Hat Clamping challenges and mitigation

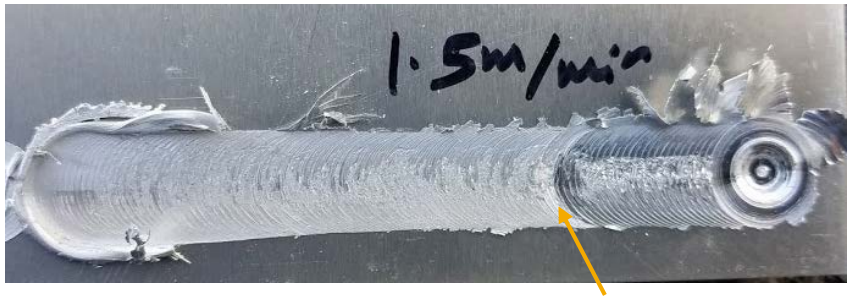


Hat-Hat-Flat parts needed additional middle clamping for flash free welds.

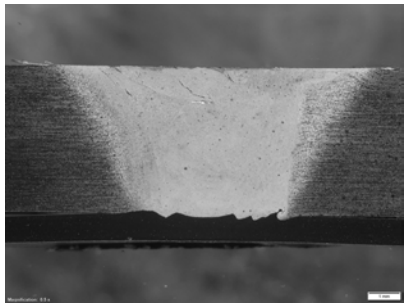


Weld edge distortion can occur at higher heat input for 6xxx and 5xxx material set. We mitigated this by lowering the heat input.

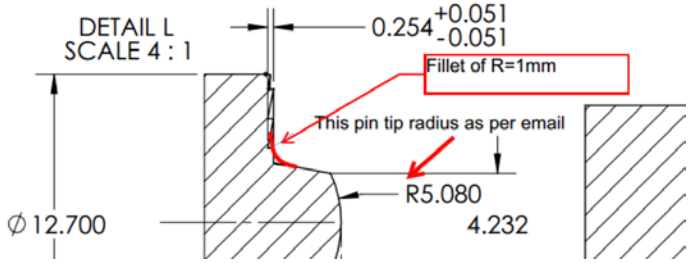
3 sheet 7055 tool failure at higher speeds



Pin broke- 13kN X force

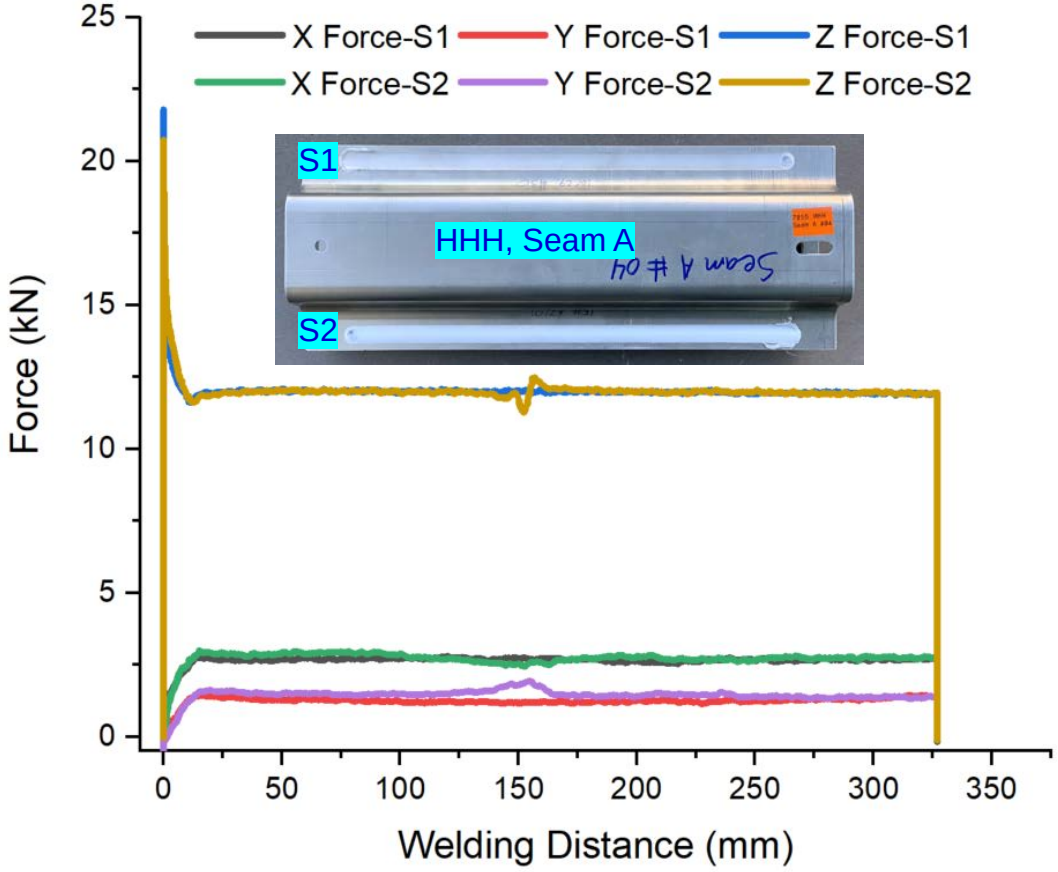


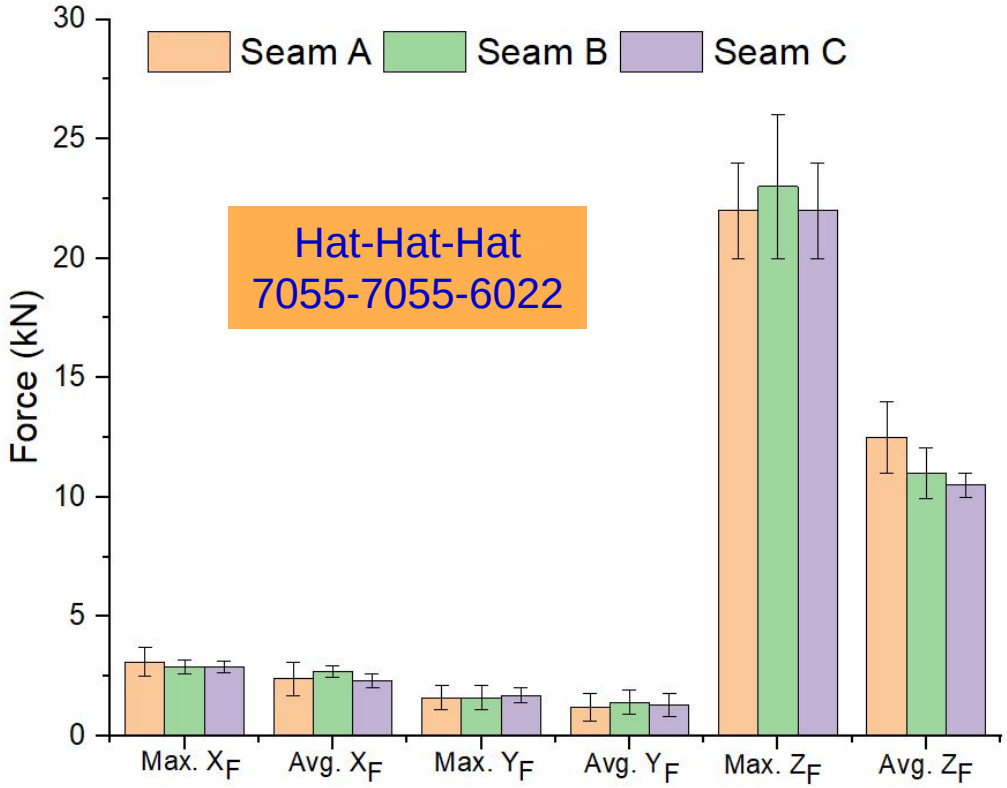
Tool pin fracture takes place near the base of pin at thread root.



Pacific Northwest NATIONAL LABORATORY

Demonstration Hat representative force data





Data from 12x weld runs in HHH